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The Study of the Influence of Intra-Abdominal Pressure to Manual Materials Handling

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Abstract. This research selects the lifting task to be the main subject. Four experiments were designed to measure which among lifting postures, lifting heights, waist-belt, and breathing control significantly influences intra-abdominal pressure (Gallagher, 1991; Lavender, Andersson and Natarajan, 1999). The experimental results were taken to be the recommendations of the manual materials handling work design. The research findings reveal that the symmetrical stoop posture is the most significant to the intra-abdominal pressure within all lifting postures. When the lifting height is increased, the intra-abdominal pressure produced relatively goes up. Also, the combination of symmetrical stoop posture, waist-belt use, and inspiration and holding at the same time is the most efficient in carrying out lifting tasks. Simultaneously, the research discovers that for any posture, the volume of the intra-abdominal pressure is much bigger when using the waist-belt compared to when it is not used. Therefore, the waist-belt design for the lifting works might be the future research approach.

Keywords: Intra-Abdominal Pressure, Manual Materials Handling, Lifting Work, ANOVA.

1. INTRODUCTION

Materials handling, regardless of the nature of occupation, whether the high tech industry, or the labor-intensive industry, is impossible without manual handling of work. This holds true especially in the labor-intensive work sites. Therefore, the use of efficient, effective, and safe handling methods is extremely important.

This study plans to realize whether the intra-abdominal pressure (IAP) can improve the muscular strength used in manual handling work, and whether the IAP causes reduction in muscular strength. This research also tries to investigate the relations between IAP and manual handling factors, such as posture, height, breathing, and waist-belt use. Finding out which factor can significantly influence IAP is the objective of this research.

2. PREVIOUS RESEARCH

Cresswell and Thorstensson (1989) individually measured IAP and the electrical signal of abdominal muscle using Tip Pressure Transducer and Electromyography (EMG). Their research findings demonstrate IAP could accompany the increases in the amount of abdominal muscles activity (Cresswell and Thorstensson, 1989). Thomson (1988) established some math models to verify the contribution of IAP in the reduction of bending momentum. The study provides evidence suggesting that IAP can reduce at least 20 percent of pressure on the spinal column and lower back muscles. In addition, the study also shows a direct ratio between longitudinal tension of abdomen and IAP and an inverse ratio with the thickness of intra-abdominal muscle. These facts demonstrate that the abdominal tension is mainly created by the IAP (Thomson, 1988).

Chang (2000) defines breathing control as holding the breath when lifting, and classifies it into inspire-hold and expire-hold. The difference between them is the amount of air occupying the lungs when holding the breath. The theory of breathing control is based on the fact that more air in the lungs is able to produce bigger abdominal pressure, and the function of the pressure can be used for reducing the vertebra load (Chang, 2000).

McGill *et al*. (1990) measured the influence of both wearing a waist-belt and breathing control to abdominal pressure and the back muscular activities. Findings show a higher peak value of abdominal pressure when holding the air compared to when continually expiring when lifting, but the electrical signal of back muscles

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tends to drop (McGill, Norman and Sharratt, 1990). Nachemson (1986) also proposes that breathing control could increase the abdominal pressure. Although there was a biomechanical benefit on the vertebra for observing breathing control, it also simultaneously presented some negative effects on abdominal pressure or physiological reaction (Chang, 2000).

Traditionally, the IAP is used for appreciating the waist-belt and being the foundation of design theory. This is an important message for the design idea of waist-belt. The IAP is a dual pressure produced by the intra-abdominal muscle and the waist-belt (Chen, 1998). The IAP can be changed along with the external load magnitude. During the manual lifting procedure, the IAP varies along with different lifting postures and loads (Wang, 1999).

The influences of using the waist-belt for lifting are as follows (Wang, 1999):

(1) Lee and Chen (1994) present a theory on the stages of lifting, and suggest the existence of different bio mechanical performance at each lifting stage. Thus, the use of waist-belt may also produce differentt influences for each lifting stage.
(2) The IAP can be increased through breathing control and the contraction of abdominal muscle. Wearing a waist-belt can help IAP because the tension of waist-belt acts upon the abdomen.
(3) The external abdominal pressure (EAP) refers to the pressure between the waist-belt and the abdomen. This external pressure is regarded as an index of waist-belt influence internal abdominal pressure (not including the influence of muscular contraction to IAP), whereas in the lifting tasks, the external abdominal pressure may respond the load of lower back. The results of EMG signal are certainly inconsistent as the waist-belt acts on the abdominal muscle group. Some results demonstrate a rise, and others show drop or insignificance.

3. METHODS

This research involves four experiments; all four individually tests for the four different combinations of the experimental factors. Seven 19-21 year-old males volunteered to be the subjects (Table 3-1). The research process is outlined below.

3.1 Research procedure

(1) Investigation and discussion of the manual handling methods and postures
(2) Planning of the experimental content and equipment
(3) Designing the experimental items, methods, and steps
(4) Experiments and the data collection
(5) Data analysis and experimental results discussion
(6) Formulation of recommendations for the improvement of manual lifting tasks

Table 3-1. Subjects' anthropometrical data.

Subject	S1	S2	S3	S4	S5	S6	S7
Stature (cm)	167	172	180	169	169	176	165
Weight (kg)	73.9	58.3	82.7	61.9	83.1	70.8	66.2
Waistline (cm)	86	71	86	80	91	76	84

3.2 Experimental equipment

(1) 115×9.5cm waist-belt (Figure 3-1)
(2) Electromyography (EMG), Bioelectric Amplifier Model AB-621G (Figure 3-2)
(3) 40×34×29 cm plastic basket (Figure 3-3)
(4) 7.5 kg×2, 5.0 kg×2, 2.5 kg×2 Dumb bell (Figure 3-3)
(5) A basic set of anthropometrical measuring instruments (Figure 3-4)
(6) Experimental tables and chairs

Figure 3-1. Lifting waist- belt

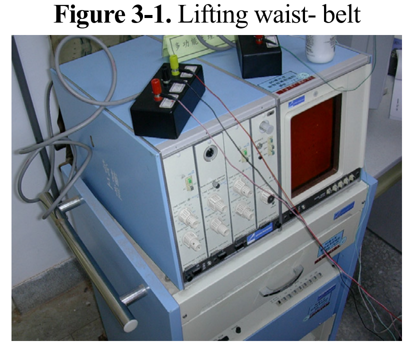

Figure 3-2. ElectromyographyEMG)

Figure 3-3. Dumb bell

Figure 3-4. Anthropometrical measuring instruments

Figure 3-5. Stoop posture

Figure 3-6. Kneeling posture

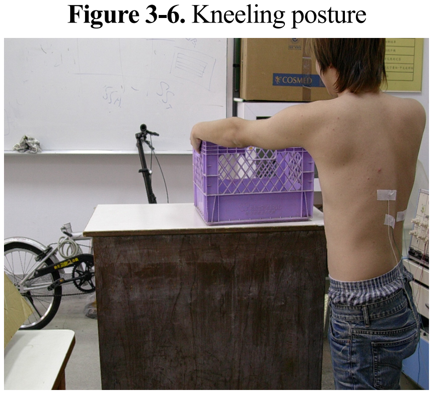

Figure 3-7. Twisting posture

3.3 Experiment design

3.3.1 Experiment I-the influence of waist-belt and lifting posture to IAP

(1) Experimental purpose

The experimental goal is to understand the significance of the intra-abdominal pressure (IAP) when the use of waist-belt is considered along with the lifting postures in the manual lifting tasks.

(2) Experimental items

A. Wearing waist-belt and Symmetrical stoop posture (Figure 3-5)
B. Wearing waist-belt and Asymmetrical stoop posture (Figure 3-6)
C. Wearing waist-belt and Kneeling posture (Figure 3-7)
D. No waist-belt and Symmetrical stoop posture
E. No waist-belt and Asymmetrical stoop posture
F. No waist-belt and Kneeling posture

(3) Experimental procedure

A. Measure and record the anthropometrical items of seven participants (Table 3-1).
B. Adjust Amplifier parameters and Time Constant to 0.03 sec (0.01-0.03sec), Sensitivity (Fine Control) to 0.1mV/DIV, and sampling rate at 1 KHz.
C. Clean the abdomen and back skin, and attach the signal receiver on the abdominal erect muscle and latissimus dorsi muscle.
D. The subject lifts the experimental items; 3 times for each item. There is a 30-second rest after each performance and a 2-minute rest after each item.
E. Record the data and calculate the statistics.

(4) Definitions of experimental items

A. Symmetrical stoop posture: a posture of bending the waist and lifting on sagittal plane.
B. Asymmetrical stoop posture: a posture of bending the waist and lifting between coronal and sagittal plane.
C. Kneeling posture: knees on the floor, torso and thighs are erect, and buttocks do not touch heels.
D. Lifting height is equal to elbow height for all postures, the lifting weight is a 10kg load put in front of the toes, and the breathing way is inspire-hold when carrying on all items.

3.3.2 Experiment II-the influence of waist-belt and lifting height to IAP

(1) Experimental purpose

The purpose of this experiment is to understand whether or not various lifting heights and the use of waist-belt can make a significant change on the intra-abdominal pressure when lifting.

(2) Experimental items

A. Wearing waist-belt and Lifting to high position
B. Wearing waist-belt and Lifting to medium height
C. Wearing waist-belt and Lifting to low position
D. No waist-belt and Lifting to high position
E. No waist-belt and Lifting to medium height
F. No waist-belt and Lifting to low position

(3) Experimental procedure—the same as Experiment I

(4) Definitions of experimental items

A. All lifting heights are measured from the ground; the low position is approximately 40cm, the medium height is around 100cm, and the high position is up to 155cm (Kassab and Drury, 1976; Ciriello and Snook, 1983).
B. A stooped-twisting posture is adopted in these lifting tasks which starts from the ground on sagittal plane and finishes at low, medium, or high place on the right coronal plane.
C. Inspiration and holding is used when lifting, a load of 10kg.

3.3.3 Experiment III-the influence of breathing way and waist-belt to IAP

(1) Experimental purpose

Two factors, waist-belt and breathing way, are analyzed in this experiment. The main purpose is to find out which factor has significant influence on the intra-abdominal pressure.

(2) Experimental items
A. Inspiration and holding with waist-belt
B. Expiration and holding with waist-belt
C. Inspiration and holding without waist-belt
D. Expiration and holding without waist-belt

(3) Experimental procedure—the same as Experiment I

(4) Definitions of experimental items
A. Inspiration and holding: inspires the air into the lung and completely fills it up then holds breath before lifting.
B. Expiration and holding: completely spits out the air and holds breath before lifting.
C. The lifting load is 10kg on the ground, and the symmetrical stoop posture is adopted.

3.3.4 Experiment IV-the influence of breathing way and lifting posture to IAP

(1) Experimental purpose

This experimental goal is to understand which factor is significant on the variation of the intra-abdominal pressure when the breathing way is compared with the lifting posture.

(2) Experimental items
A. Symmetrical stoop posture and Inspiration and holding
B. Symmetrical stoop posture and Expiration and holding
C. Stooped twisting posture and Inspiration and holding
D. Stooped twisting posture and Expiration and holding
E. Kneeling Posture and Inspiration and holding
F. Kneeling Posture and Expiration and holding

(3) Experimental procedure-the same as Experiment I

(4) Definitions of experimental items
A. Kneeling posture (Figure 3-6): knees on the floor, torso and thighs are erect, and buttocks do not touch heels.
B. Stooped twisting posture (Figure 3-7): it starts from the ground on sagittal plane and finishes at elbow high position on the right coronal plane (turns 90 degrees).
C. Symmetrical stoop posture (Figure 3-5): bending the waist and lifting from the ground to elbow height on sagittal plane.
D. Lifting load is 10 kg, without waist-belt.

4. RESULTS

4.1 Experiment I-the influence of waist-belt and lifting posture to IAP

Table 4-1 and Table 4-2 show the experimental results. The data is expressed in muscular voltage value (mV). The data suggests that the waist-belt causes the abdomen to produce an increased muscle tension, the intra-abdominal pressure.

Table 4-1. Experiment I abdomen data

Summary	Symmetry Stoop	Asymmetry Stoop	Kneeling	Total
Wearing waist-belt				
Subject	7	7	7	21
Total	5.42	4.25	3.21	12.88
Mean	0.774	0.607	0.459	0.613
Variance	0.1155	0.0392	0.0430	0.0768
No waist-belt				
Subject	7	7	7	21
Total	3.39	3.53	1.59	8.51
Mean	0.484	0.504	0.227	0.405
Variance	0.0070	0.0262	0.0003	0.0268

Table 4-2. Experiment I back data

Summary	Symmetry Stoop	Asymmetry Stoop	Kneeling	Total
Wearing Waist-belt				
Subject	7	7	7	21
Total	5.22	5.69	2.73	13.64
Mean	0.746	0.813	0.390	0.650
Variance	0.1622	0.2273	0.0328	0.1628
No Waist-belt				
Subject	7	7	7	21
Total	4.37	7.26	1.95	13.58
Mean	0.624	1.037	0.279	0.647
Variance	0.0114	0.1498	0.0043	0.1506

Using the waist-belt to reduce the dynamic back muscle tension is certainly not the case for asymmetrical posture. The kneeling posture produces the least tension on the abdomen and back.

4.2 Experiment II-the influence of waist-belt and lifting height to IAP

Table 4-3 and Table 4-4 show the 2nd experimental results, also reported in mV. The measurements reveal that wearing a waist-belt while lifting to a high position (155cm) produces the biggest intra-abdominal pressure, but the smallest back muscle tension. The back muscle tension is at peak when lifting to the high position without waist-belt.

Table 4-3. Experiment II abdomen data

Summary	Low	Medium	High	Total
Wearing Waist-belt				
Subject	7	7	7	21
Total	2.74	4.13	5.94	12.81
Mean	0.391	0.590	0.849	0.610
Variance	0.0052	0.1178	0.2158	0.1384
No Waist-belt				
Subject	7	7	7	21
Total	4.51	2.69	3.07	10.27
Mean	0.644	0.384	0.439	0.489
Variance	0.1352	0.0056	0.0048	0.0568

Table 4-4. Experiment II back data

Summary	Low	Medium	High	Total
Wearing Waist-belt				
Subject	7	7	7	21
Total	6.52	7.55	4.28	18.35
Mean	0.931	1.079	0.611	0.874
Variance	0.0939	0.2898	0.0326	0.1648
No Waist-belt				
Subject	7	7	7	21
Total	5.69	4.5	7.08	17.27
Mean	0.813	0.643	1.011	0.822
Variance	0.1149	0.0593	0.3044	0.1674

4.3 Experiment III-the influence of breathing way and waist-belt to IAP

The third experiment aims to determine whether or not waist-belt coupled with breathing control have an additional effect on IAP. Table 4-5 and Table 4-6 demonstrate the experimental results. The value obtained for combination of inspiration and holding, and wearing waist-belt is twice than that of expiration and holding, but the variation of IAP is smaller when lifting without waist-belt. Thus, the factor of inspiration and holding may certainly promote IAP. The inspire-hold also may reduce the contraction tension of latissimus dorsi muscle, but the back muscle tension may be slightly increased when wearing the waist-belt.

The experimental results demonstrate that the combination of symmetrical stoop posture and inspiration and holding produced the biggest IAP (Table 4-7 and Table 4-8). The difference between inspiration and expiration is biggest when using the symmetrical stoop posture, but other postures are smaller or even opposite. The difference in the contraction tension of back muscle is high when comparing inspiration with expiration.

Table 4-5. Experiment III abdomen data

Summary	Waist-belt	No Belt	Total
Inspiration			
Subject	7	7	14
Total	6.50	5.68	12.18
Mean	0.929	0.811	0.870
Variance	0.0593	0.2928	0.1662
Expiration			
Subject	7	7	14
Total	3.08	4.63	7.71
Mean	0.440	0.661	0.551
Variance	0.0270	0.1247	0.0832

Table 4-6. Experiment III back data

Summary	Waist-belt	No Belt	Total
Inspiration			
Subject	7	7	14
Total	5.41	5.17	10.58
Mean	0.773	0.739	0.756
Variance	0.2928	0.3113	0.2791
Expiration			
Subject	7	7	14
Total	6.14	5.94	12.08
Mean	0.877	0.849	0.863
Variance	0.2298	0.1621	0.1811

4.4 Experiment IV-the influence of breathing way and lifting posture to IAP

Table 4-7. Experiment IV abdomen data

Summary	Symmetry Stoop	Stooped Twisting	Kneeling	Total
Inspiration				
Subject	7	7	7	21
Total	6.59	4.02	2.89	13.50
Mean	0.941	0.574	0.413	0.643
Variance	0.5858	0.1456	0.0896	0.2977
Expiration				
Subject	7	7	7	21
Total	2.65	3.81	4.04	10.5
Mean	0.379	0.544	0.577	0.500
Variance	0.0338	0.0690	0.2764	0.1217

Table 4-8. Experiment IV back data

Summary	Symmetry Stoop	Stooped Twisting	Kneeling	Total
Inspiration				
Subject	7	7	7	21
Total	3.15	4.31	2.01	9.47
Mean	0.450	0.616	0.287	0.451
Variance	0.0261	0.0739	0.0066	0.0509
Expiration				
Subject	7	7	7	21
Total	2.50	2.22	1.75	6.47
Mean	0.357	0.3171	0.250	0.3081
Variance	0.0030	0.0048	0.0033	0.0054

5. ANALYSIS AND DISCUSSION

5.1 Experiment I-the influence of waist-belt and lifting posture to IAP

From the results (table 4-1), the stoop posture produces more tension than kneeling posture when using a waist-belt. The average voltage value when wearing waist-belt is greater than without waist-belt on the symmetrical posture (0.77 > 0.48), and the asymmetrical posture is the same as symmetrical posture (0.60 > 0.50), but the effectiveness of waist-belt is actually smallest for kneeling posture.

From Table 5-1, the ANOVA analysis of the contraction tension of abdomen muscle (Reliability 95%) demonstrates that both use of waist-belt and posture are significant. This shows effectiveness of using the waist-belt as an auxiliary tool on the manual lifting tasks, while the stoop posture demonstrates the auxiliary value of waist-belt more than the others.

Table 5-1. Experiment I abdomen ANOVA

Source	SS	DF	MS	F	P	F_0
Waist-belt	0.4547	1	0.4547	11.7957	0.0015	4.1132
Posture	0.6199	2	0.3098	8.0364	0.0013	3.2594
Interaction	0.0641	2	0.0320	0.8321	0.4433	3.2594
Error	1.3877	36	0.0385			
Total	2.5260	41				

However, the use of waist-belt is certainly not significant on the data analysis for back tension. Analysis of abdomen data shows that IAP influences the abdominal muscle tension, and the waist-belt truly enhances the IAP to increase the abdominal muscle tension. The opposite is true for back tension data analysis (Table 5-2); the waist-belt is not helpful for back muscle strength although posture is still a significant factor for back muscle activities. Table 4-2 reveals that the stoop posture needs more back muscle strength to lift than the kneeling posture. Therefore, the lifting load must be suitably designed when adopting the stoop posture in lifting to avoid the risk of lower back injury.

Table 5-2. Experiment I back ANOVA

Source	SS	DF	MS	F	P	F0
Waist-belt	8.57E-05	1	8.57E-05	0.0009	0.9766	4.1132
Posture	2.4712	2	1.2356	12.612	7.06E-5	3.2594
Interaction	0.2710	2	0.1355	1.3833	0.2638	3.2594
Error	3.5269	36	0.0980			
Total	6.2692	41				

5.2 Experiment II-the influence of waist-belt and lifting height to IAP

The ANOVA results demonstrate the lack of influence of waist-belt and lifting height (Table 5-3 and Table 5-4). The experimental data (See Table 4-3 and Table 4-4) exhibits variation in the data for waist-belt effect at different lifting heights, which may be because lifting activities need different parts of abdominal muscles from low to high places, also the way muscle contracts and the inconsistency of the stature of subjects. Therefore, the data is unable to present a significant result.

Table 5-3. Experiment II abdomen ANOVA

Source	SS	DF	MS	F	P	F_0
Waist-belt	0.1536	1	0.1536	1.9025	0.1763	4.1132
Height	0.1923	2	0.0962	1.1912	0.3156	3.2594
Interaction	0.8066	2	0.4033	4.9953	0.0122	3.2594
Error	2.9066	36	0.0807			
Total	4.0592	41				

Table 5-4. Experiment II back ANOVA

Source	SS	DF	MS	F	P	F_0
Waist-belt	0.0278	1	0.0278	0.1862	0.6687	4.1132
Height	0.0292	2	0.0146	0.0977	0.9071	3.2594
Interaction	1.2459	2	0.6230	4.1770	0.0234	3.2594
Error	5.3691	36	0.1491			
Total	6.6719	41				

Observing the data obtained for high position (155cm), the average pressure exerted in the abdominal muscle is 0.85mV; 0.61mV for back muscle when using the waist-belt. The average abdominal muscle tension produced is 0.44mV and 1.02mV for back muscle when not using the waist-belt. Data shows a reduction in the contraction tension of lower back muscle when the IAP is increased. Therefore, it should complement the use of waist-belt to possibly reduce the lower-back pressure when the lifting height exceeds the elbow height.

5.3 Experiment III-the influence of breathing way and waist-belt to IAP

When using a waist-belt, the average tension on the abdominal muscles of the combination of inspiration and holding is much higher than expiration and holding (0.92 > 0.44). The muscular voltage value of inspiration and holding is also greater than the expiration and holding without the waist-belt (0.81 > 0.66), as shown in Table 4-5. On the other hand, Table 5-5 shows that inspiration and holding is extremely significant when considering the influence of IAP, but the waist-belt appears to be not a significant factor. Thus, the result reveals the effectiveness of breathing control than the waist-belt when considering IAP.

Table 5-5. Experiment III abdomen ANOVA

Source	SS	DF	MS	F	P	F_0
Breath	0.7136	1	0.7136	5.6660	0.0256	4.2597
Waist-belt	0.0190	1	0.0190	0.1511	0.7009	4.2597
Interaction	0.2006	1	0.2006	1.5928	0.2191	4.2597
Error	3.0227	24	0.1259			
Total	3.9559	27				

The voltage value of inspiration is smaller than the expiration on back muscles (0.77 < 0.88 and 0.74 < 0.85) regardless of waist-best use (Table 4-6). This suggests that inspiration promotes IAP in order to reduce the contraction tension of back muscles, even though breathing control and waist-belt use are not significant on back muscles (Table 5-6). Therefore, inspiration and holding are important lifting skills that promote IAP and decrease lower-back injury risk for manual lifting tasks.

Table 5-6. Experiment III back ANOVA

Source	SS	DF	MS	F	P	F_0
Breath	0.0804	1	0.0804	0.3227	0.5753	4.2597
Waist-belt	0.0069	1	0.0069	0.0278	0.8691	4.2597
Interaction	5.71E-05	1	5.71E-05	0.0002	0.9880	4.2597
Error	5.9761	24	0.2490			
Total	6.0634	27				

5.4 Experiment IV-the influence of breathing way and lifting posture to IAP

The muscular voltage of inspiration and stoop posture, and inspiration and twisting posture is greater than their combination with expiration; but, the kneeling posture has the opposite change on the abdomen (Table 4-7 and Table 4-8). That demonstrates the stronger IAP produced to support the upper trunk to rise by the assistance of inspiration when bending the waist. However, the variation of IAP for kneeling posture is not obvious when inspiring, because of the smaller bending angle of kneeling posture. Therefore, the study shows that bigger bending angle can make the inspiration effect bigger. Table 4-7 shows a large variation in data; therefore, breathing and posture are not significant factors (Table 5-7). Table 5-8 shows significant analysis of two factors, demonstrating the importance of both breathing skill and lifting posture as work design factors in the manual lifting tasks.

Table 5-7. Experiment IV abdomen ANOVA

Source	SS	DF	MS	F	P	F_0
Breath	0.2143	1	0.2143	1.0712	0.3076	4.1132
Posture	0.1937	2	0.0968	0.4841	0.6202	3.2594
Interaction	0.9922	2	0.4961	2.4798	0.0980	3.2594
Error	7.2018	36	0.2001			
Total	8.6019	41				

Table 5-8. Experiment IV back ANOVA

Source	SS	DF	MS	F	P	F_0
Breath	0.2143	1	0.2143	10.927	0.0022	4.1132
Posture	0.2862	2	0.1431	7.2963	0.0022	3.2594
Interaction	0.1327	2	0.0664	3.3840	0.0450	3.2594
Error	0.7060	36	0.0196			
Total	1.3392	41				

Table 5-9 shows correlation coefficients between subjects' stature and the abdominal muscle volt for lifting heights. Results show that low position has higher correlation (r = 0.69) than medium and high position. It means that subjects' stature has an effect on low lifting height, and may influence experimental results when the differences within the subjects' statures are big. Therefore, it will be reasonable as the stature of subjects is selected to be even.

Table 5-9. Correlation coefficients between subjects' stature and the lifting heights

Lifting Height	Subjects' Stature
Low position (40cm)	0.6911
Medium position (100cm)	0.2934
High position (155cm)	0.0838

6. CONCLUSION

6.1 Conclusion of research

The research designed four experiments to measure the influence of four factors, namely, posture, height, waist-belt, and breathing to IAP when carrying on the manual lifting tasks. These factors are summarized in the Table 6-1.

Table 6-1. Experimental factors

Experimental Factors and Levels				
Breath	Inspiration		Expiration	
Waist-belt	Wearing		No	
Posture	Symmetry Stoop	Asymmetry Stoop	Kneeling	Stooped Twisting
Height	Low Position	Medium Height	High Position	

Considering posture, experimental results show symmetrical stoop posture is the most significant factor to influence IAP. The asymmetrical stoop posture and stooped twisting posture can cause back muscle to increase contraction tension. Therefore, the symmetrical posture must be adopted to reduce the risk, if it is necessary to bend the waist to lift a heavy load. For lifting height, the produced IAP and back muscle tension relatively becomes bigger when the vertical moving distance is longer. Hence, directly lifting to a high place should be avoided.

Adopting the lifting waist-belt and inspiration and holding to carry on manual lifting tasks can produce the best effect. The IAP of the combination of these factors is obviously much bigger than the combination without waist-belt, and expiration and holding, but the data for back tension shows significant reduction of pressure. Therefore, inspiration and holding is recommended when lifting.

Synthesizing three experiments for waist-belt use, the study discovers that its use not promotes a tremendous influence to the IAP, but can also slightly increase the contraction tension of back muscle. Thus, the waist-belt can assist the abdomen muscle to hold the biggest IAP when lifting.

The study also finds out that waistband use can produce higher IAP than without waist-belt for any lifting posture. Considering lifting height, the waist-belt should be worn when lifting loads to a higher place; then, it may generate a bigger IAP by waist-belt to assist the upper torso to rise.

Table 6-2. Optimal settings of selected lifting factors

Lifting Factors	Optimal Setting
Lifting Posture	Symmetrical posture
Lifting Height	Short vertical moving distance
Breathing Control	Inspiration and holding
Lifting Waist-Belt	Wearing a waist-belt

In summary, the statement above can be synthesized to several viewpoints and optimal settings listed below (Table 6-2):

1. Lifting posture – symmetrical stoop posture significantly influences IAP for all the postures
2. Lifting heights-as lifting height increases, the need for IAP also increases
3. Breathing control-it can promote the most IAP when adopting inspiration and holding techniques to carry on the lifting tasks in order to reduce the contraction tension of back muscles
4. Lifting waist-belt – for any lifting posture and lifting height, IAP is higher when using the waist-belt than without waist-belt

6.2 Recommendations of research

1. The symmetrical posture should be adopted when carrying on a manual lifting task.
2. Lifting tasks should be designed to two-stage handling when there is a risk to harm the lower back of workers at a lifting height.
3. The waist-belt should be put on to assist the handling if the load must be directly lifted to a high place.
4. It is recommended to inspire and hold the air in the lung before lifting.
5. Stoop and twisting posture should be avoided for any lifting task in order to prevent the back injury.
6. When circumstance permit, it strongly suggested to wear a waist-belt when carrying on any lifting task.

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